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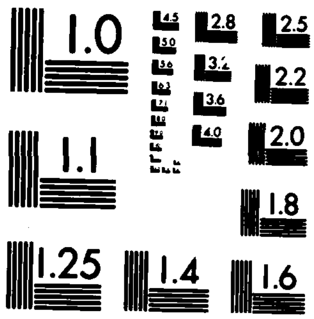
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RSRE MEMORANDUM No. 3530

ROYAL SIGNALS & RADAR ESTABLISHMENT

REVIEW OF CLIMATIC PROTECTION TECHNIQUES FOR ELECTRONIC EQUIPMENTS

Author: E Napper

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MINISTRY OF DEFENCE,
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Title: REVIEW OF CLIMATIC PROTECTION TECHNIQUES FOR ELECTRONIC EQUIPMENTS

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Date:

SUMMARY

This memo reviews the problem of protecting Military electronic equipment, when deployed and in store from adverse climatic environments, the major factor being protection from the effects of water and water vapour in the atmosphere aided by temperature effects.

The effects of moisture on equipments, achieving and maintaining a dry interior, sealing standards, water vapour barriers, desiccation, drying-out procedures and humidity indication are considered, together with allied aspects.

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RSRE MEMORANDUM NO 3530

REVIEW OF CLIMATIC PROTECTION TECHNIQUES FOR ELECTRONIC EQUIPMENTS

E Napper

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1 INTRODUCTION

Military electronic equipments and weapons are required to withstand wide extremes of climatic and mechanical hazards arising from the deployment pattern of depot storage, distribution and field use, with complementary maintenance and repair aspects.

The equipment design objective is to obtain the highest possible equipment availability and reliability with the lowest overall cost over the life of the equipment. This is a complex equation of development, production, maintenance and repair costs.

Mechanical hazards in the form of handling and transportation shock and vibration are well understood and there are established design approaches to minimise the effects of these hazards.

As far as climatic hazards are concerned, these are well known and obviously related to geographical location. They can be stated as high temperature - ambient and induced by equipment operation, low temperature, barometric pressure change, humidity and precipitation, usually occurring in combination.

Temperature effects are well understood and are a resolvable design problem. However, the effects of high humidity, usually in conjunction with high temperature and precipitation in the form of liquid water are generally considered as the main aspect of climatic protection and the expression climatic protection is used in that context throughout this memo.

Water and water vapour are undesirable within equipments because of their deleterious effects on materials, components and devices and eventual reduction of reliability and availability. Climatic protection embraces a deep understanding of the effects of moisture in equipment and up to the mid/late 60s, the approach to providing equipment climatic protection was not wholly coherent or, in some cases logistically sensible. There was a need to rationalise procedures in this area.

There are several reasons for this re-evaluation such as:

a. The changes in the British government's overseas policy which resulted in the virtual disappearance of overseas Military bases and operational areas outside Europe. Apart from NATO/NW Europe it was envisaged that any worldwide involvement would be minimal.

b. The fast developing changes in electronic equipment design arising from semiconductor development. The resulting smaller but often more highly complex equipments were making more use of light-weight construction and plastics based structures and also caused a complete change in maintenance/repair policy.

c. Subtle changes in transportation techniques arising from greater use of containerisation, pallet loads and air transport especially helicopters.

d. Extension of the 'sealed for life' philosophy used for ammunition to weapons (especially GW) and mobile equipments.

The attempt to rationalise the climatic protection problem took the form of a long-term R&D programme sponsored by RSRE and mainly carried out by extramural

contract which divided into four areas:

e. Processes by which water and water vapour gain access to equipments.

f. Effects of moisture in equipments.

g. Desiccation and drying-out techniques.

h. Measurement and detection of humidity.

At the start, it was realised that an accurate, sensitive and adaptable means of measuring water content of the atmosphere and humidity conditions within sealed equipments would be required. Since no available equipment was suitable, the sweep-gas electrolytic hygrometer technique was developed and refined to a highly useful tool (see paragraph 4.3).

For ground-based equipment there are broadly two separate areas of climatic protection:

i. the packaging for transit and storage, etc; and

j. the equipment requirement when deployed for action.

The difference is one of emphasis; equipment intended for a stringent field operational role such as mobile army radars may have a high degree of in-built protection and require a minimum of packaging for the store and transit phases. Conversely, if it has relatively little in-built protection the packaging requirements dominate.

Climatic protection is also applicable to aircraft installed equipment, with enhanced emphasis on the sealing and breathing aspects.

The conditions against which MOD equipment is designed are essentially stated in DEF 001 and DEF 003 with demonstration of capability by tests in DEF 07-55, MIL STD 875, etc, as well as the equipment specification.

2 NATURE OF THE PROBLEM

2.1 CLIMATIC CONDITIONS

The climatic hazards against which equipment must be protected arise almost wholly from water and water vapour, and the effects are worsened by temperature changes.

Free water arises from precipitation - rain, fog, snow and hail - or from water vapour condensed onto cold surfaces. Water vapour is always present in the atmosphere but in especially large quantities in the tropics.

The distinction between water and water vapour is not important because of the ready conversion of one to the other.

Temperature changes can be due to diurnal cycling, solar radiation, radiation cooling and wind, or from self generated heat due to equipment operation, but are only important as a climatic hazard when water/water vapour is present in quantity. In a hot dry or extreme cold environment the need for climatic protection is reduced.

The extreme climatic conditions (1% risk of occurrence) categorised in DEF STAN 00-1 (Ref (1)) are less important than average levels since climatic protection is needed over a longer term than is implicit in the 4 days per year of the DEF STAN 00-1 conditions.

Hot/wet conditions with temperature changes are the worst case and it is helpful to classify the protection as suitable for temperate or hot/wet conditions. The most important single parameter is atmospheric water vapour pressure which relates to absolute humidity or the water content of the atmosphere and varies from approximately 10 mb temperature to 30 mb tropical hot/wet (0.008 grams to .02 grams per litre of air water content).

These figures change seasonally but from a climatic protection viewpoint can be considered substantially constant over a period of weeks in most locations; and are usually related to seasonal patterns.

2.2 EFFECT ON EQUIPMENT

The effects of water/water vapour on electrical, electronic and optical equipment can be considered under three headings:

a. Corrosion - metallic materials

In practice corrosion or electrolytic degradation of metallic surfaces and between dissimilar metals in contact caused by water is generally accelerated by other contaminants in the atmosphere, ie marine salt, industrial pollutants. Corrosion can be minimised by correct choice of materials and finishes.

b. Degradation of non-metallic materials which may be either temporary or permanent.

Includes: Mechanical deterioration due to dimensional change.

Change of structure.

Deterioration of finishes.

Electrical deterioration in the bulk of insulation material and of surface resistivity.

Change of electrical parameters of circuit elements and unwanted interaction between them.

Misting of glass surfaces of optical items.

c. Biodeterioration

High humidity and heat encourage mould growth on surfaces, rot in textiles and cellulose based materials, contamination of oils and lubricants, and in extreme cases fouling of mechanisms.

Of these a.eas, degradation is the most important, but all three are usually interlinked. Examples are mould growth on optical surfaces causing not only misting, but etching of glass surfaces, and the effects of moisture on plastic encapsulated semiconductor devices, causing failure.

In practice, corrosion does not occur below 60% relative humidity or mould growth below 75% and it is generally accepted that for reliable operation and long life the relative humidity within an equipment should not exceed 50%. This condition applies over the entire operational temperature range of the equipment which may typically extend from -40°C to +70°C.

2.3 HOW MOISTURE GAINS ACCESS

The prime function of any climatic protection measures is to minimise the penetration of moisture into an equipment so that it can function with maximum reliability (moisture is hereon used as a term embracing water and water vapour).

The first step in any protection system is to enclose the equipment in a case or container. Container is used in the widest sense as a structure providing protection either as an integral part of the equipment or separately enclosing the equipment and providing the major part of the protection.

For items relatively unaffected by moisture, the case may only need to shield the interior from rain and spray. This form of construction is considered open or unsealed. (Strict definitions of sealing are given in BS 2011 Part 2 Test Q Sealing, but the sealing grades defined therein are only partly applicable to the climatic protection problem.)

A sealed equipment is one in which an attempt has been made to isolate the equipment interior from ambient. The standard of sealing is relative, only by making a metal fusion or similar seal is it possible to completely prevent the ingress of moisture.

NOTE: The expression 'hermetic seal' should be avoided in this context as meaning air tight, and this does not fully preclude moisture penetration.

See for discussion on sealing standards paragraph 3.5.

In an equipment container there are three ways apart from gross leaks, (see Figure 1) in which water can enter:

a. Diffusion;

b. Capillary action; and

c. Breathing.

Diffusion

For most of its life the relative humidity within the equipment will be lower than in the surrounding atmosphere, creating an inward water vapour pressure gradient, and moisture will enter the container by diffusing through gasket materials, through sealing imperfections such as covers, actuation points, shaft seals, connector and panel-mounted components and also through the container itself unless it is metal. The rate at which moisture enters will depend upon the water vapour transmission rate of the materials used and the water vapour pressure gradient.

It is important to recognise that pressurising a container will not prevent water vapour from entering by diffusion. This is because the behaviour of the different gases and vapours in the atmosphere is governed by Dalton's Law of Partial Pressures. This Law states that each constituent seeks to achieve its own pressure equilibrium independently of the others. Therefore, if a container contains a higher pressure of gas 'A' and a lower pressure of gas 'B' than in the surrounding atmosphere, there will be a tendency for gas 'A' to pass outwards and gas 'B' to pass inwards, and these movements can take place simultaneously and without interaction by diffusion through the gasket material. Thus if the partial pressure difference is inward, water vapour will diffuse into a container regardless of pressurisation.

Water vapour will also diffuse through leaks in a container at a rate depending both upon the size and the shape of the leak. The size effect is obvious, but the shape effect is due to the rate of diffusion being less through a tube than through a hole. The rate of diffusion is in fact inversely proportional to the length/bore ratio of a tube, and for ratios greater than 10:1 the rate of diffusion is very low.

Capillary Action

Drops of liquid water covering a leak can enter a container solely due to capillary action (ie in the absence of an inward pressure difference). Capillary action is basically due to the molecules of water being more strongly attracted to the molecules of the substance surrounding the leak path or 'tube' than to each other, and thus they tend to move along the 'tube'. The molecular attraction depends upon the substance, and is large for one that water 'wets' but negative (ie a repulsion) for one that sheds water readily. This is why a water-repellent coating can eliminate capillary action (see section 3.5), and why capillary action is strongly dependent on the presence or otherwise of contamination on the adjoining surfaces.

Breathing

Breathing takes place through container sealing imperfections as the atmospheric pressure rises and falls. Dry air is expelled from the container as the barometric pressure falls, and is replaced by wetter air from outside as it rises again. This is a virtually continuous but fairly slow process. Larger and more rapid pressure changes and consequently larger air displacements and greater moisture uptake, are caused by temperature changes (eg due to solar radiation, changes in air temperature or internally generated heat due to equipment operation). If an exposed equipment container cools by radiation to the sky below the dewpoint of the surrounding air (a situation that occurs in late evening or during the night in the UK at certain times in the year, and is a frequent occurrence in hot wet areas such as the Arabian Gulf) condensation forms on the outside of the container. The falling pressure within the container can suck in this liquid water if leaks exist. Equipments installed in, or likely to be transported by air are fitted with a breather valve to relieve internal pressure during climb and descent in an aircraft and this can also result in the exchange of dry for moist air.

In most normal situations, nearly all water/water vapour enters a container by breathing - the other two mechanisms are usually insignificant in comparison.

2.4 TYPES OF EQUIPMENT

From the climatic protection viewpoint, equipments can be categorised as 'Unsealed' and 'Sealed'.

Unsealed equipment usually only provides protection from free water in the form of rain or spray. This category also includes rack or cupboard mounted equipment installed in buildings, open or ventilated construction, some airborne equipment units, and items of bench test gear - all of these operate in an environment which is conditioned in a loose sense and are outside the scope of this document.

Sealed equipments can be defined as designs in which an attempt is made to reduce the ingress of water vapour and also other contaminants in adverse environments. They may be fully sealed or partially sealed and may or may not be desiccated and/or fitted with pressure relief facilities (see paragraph 3.5 for details of sealing standards).

The kind of protection provided depends on the anticipated deployment, but the following points should be noted:

a. The best attainable standards of sealing are essential if the equipment must operate unprotected in a field or battlefield environment (eg mobile telecommunication, guided weapon and field radar equipment).

b. To avoid the weight penalty of making airborne and mobile telecommunication equipment containers strong enough to withstand flight and operational pressure differentials, some with means of pressure relief is usually fitted.

c. Conditions within storage depots are usually not severe because of the stable environment although storage may be for long periods in peacetime. However, under war conditions temporary storage will be widely used and conditions, especially in the tropics, may be very severe though of short duration.

3 CLIMATIC PROTECTION TECHNIQUES

3.1 HOW TO ACHIEVE A DRY INTERIOR

In equipment design, from a climatic protection viewpoint, the first priority is to minimise the water input in service and then to make provision for absorbing and removing the water that does enter.

However, there is also a manufacturing and production aspect. At the manufacturing stage, the equipment components will have a natural level of water content due to hygroscopicity and surface adsorbtion and it is good practice to remove most of this water by means of drying-out techniques before sealing up the equipment. This is also important after opening up equipments for repair and maintenance in wet atmospheres. See paragraph 4.2 for more complete discussion.

The process of absorbing the unwanted water to obtain a dry interior is known as Desiccation and utilises a water absorbing material which does not readily give up the absorbed water. The action can be chemical, the water combining irreversibly with the material to form another chemical compound.

Alternatively, the water may be r[illegible]ned in a porous molecular structure from which it can only be removed [illegible] difficulty by the application of heat.

Moisture can be removed from an equipment interior by circulating dry gas through it. This is an accepted drying-out process. The system can be made closed circuit and the returned gas dried by a desiccant. This approach is applicable to large equipments or systems such as computer and telephone exchanges.

It will be evident that for any drying system to operate in an efficient and economical manner a reasonable degree of sealing of the equipment from the wet atmosphere is needed.

Desiccation techniques and materials are discussed in some length in the next section.

3.2 PRINCIPLES OF DESICCATION

Desiccation in simple terms is a means for keeping the interior of the equipment or package as dry as practicable. It is generally accepted that the relative humidity should not exceed 50% for satisfactory life and reliable operation. This is a somewhat arbitrary level set during World War II when problems with equipments in tropical areas were being experienced. It is now known that its application to second and third generation electonics and allied equipments gives an inbuilt safety factor.

As a general statement, below 50% RH corrosion and allied degradation is very slow, dimensional instability of materials and deterioration of electrical properties is not significant below 80% RH, and biodeterioration occurs only above 90% RH. Similarly, conditions for equipment in store are only considered poor if the RH level is in excess of 60-65% RH.

The generally accepted 50% RH level requires further qualification.

In an ideal, perfectly sealed, volume containing moist air, the relative humidity will vary with temperature, and when a sufficient low temperature is reached, 100% RH and condensation conditions occur. In a practical equipment, all the interior surfaces and items tend to be hygroscopic to some extent and modify this process. The effect is that the relative humidity does not change by the expected amount when the temperature varies. Also the thermal storage capacity of the equipment's contents further moderates the actual changes in relative humidity. This effect is well illustrated by the 'lag-loop' presentation devised by Mueller (Ref (2)), and in which the changes in air temperature and relative humidity inside a container are graphically plotted. Figure 2 shows a comparison between the lag-loops obtained from two different sealed containers during outdoor exposure.

One container was a completely empty thin walled metal box and the other a similar volume sealed Digital Computer Unit with PCBs and desiccators removed, leaving just the cable looms and connectors. It can be seen that the presence of these items was sufficient to virtually stabilise the relative humidity d[illegible]ring temperature change (Ref (27)).

The amount of water that can be absorbed by the internal items and surfaces of an equipment is finite and the internal relative humidity will be determined initially by the atmosphere to which the items have been exposed. As water will continue to gain access into an equipment by breathing and diffusion at a rate dependent upon the water vapour pressure differential between internal and external ambient, the 'life' (ie the time for the internal RH to reach 50%) of an equipment relying solely on its own hydroscopic nature can be very short. Therefore, in the practical situation, in order to increase the 'life' of an equipment to a reasonable period of time, a particular type of hydroscopic material - a desiccant - is placed inside the equipment.

The desiccant, in fact, fulfils a number of functions:

a. Reducing the internal relative humidity to an initial level well below 50%.

b. Due to its high capacity for absorbing water, it can cope with water ingress over a long period of time.

c. It reduces the variations in relative humidity due to temperature changes.

3.3 DESICCANT MATERIALS

A large number of substances are capable of taking up water and water vapour to some degree and have the potential to provide climatic protection. Practice defines the term desiccant as substances which are highly efficient in taking up a high percentage of their dry weight of water and which do not readily give up the water they contain.

This rules out as desiccants most hygroscopic materials - generally cellulosic or organic which have limited absorption capability and readily return the water to atmosphere.

Strictly this definition includes chemical drying agents, but in general these are unsuitable because of form or aggressiveness for protection purposes. Only quick lime (calcium oxide) has been used to any extent, and it has great disadvantages.

This leaves the only class of substances which are of interest for climatic protection purposes - physical absorbents.

a. Adsorption

A gas or vapour which comes into contact with a solid substance has a tendency to collect on the surface of the solid. This phenomenon is known as adsorption. The more familiar term 'absorption' relates to the incorporation of a gas of vapour within the fibres of a material, thus forming a solid solution. Desiccants are an extremely porous type of adsorbing solid with very large internal surface areas. Different pore sizes enable particular materials to have an affinity for specific vapours according to the size of the adsorbed molecule. There are three desiccants with a high affinity for water vapour that are approved for service use - silica gel (BS 2540, Ref (3)), molecular sieves (CS 8107, Ref (5)) and activated alumina (TS 487, Ref (4)) (alternatively called activated clay).

b. Silica Gel

This is the most commonly used desiccant material which is prepared in granular form from a sodium silicate solution reacted with a mineral acid and is essentially pure silica containing chemically combined water in its structure. The porous structure is such that a 1.5 mm dia particle has a surface area approaching 2.5×10^5 that of its exterior. It can absorb approximately 30% of its own weight of water from a surrounding atmosphere at 50% RH at normal temperatures and its characteristic (Figure 3) is such that an almost linear relationship of water uptake to equilibrium relative humidity to 50% RH is obtained.

When used in an enclosed space, the interchange of water vapour between the silica gel and the air will hold relative humidity almost constant over a wide temperature range. This means that for calculation of silica gel requirements the equipment designer can use the data relating to 25°C, secure in the knowledge that even if ambient temperature varies greatly, internal relative humidity will be largely unaffected. This procedure will also be valid for an equipment fitted with a breathing desiccator (see paragraph 3.4) because the internal atmosphere is effectively static for most of the time.

Silica gel can be reactivated for reuse by heating to a temperature of +140°C. However, reactivation of material for equipment desiccation has serious disadvantages and fresh material to replace spent desiccant is to be preferred (see section 4.3).

The granules are not physically strong and tend to break down and form dust during vibration and shock. In packaging and equipment applications granular silica gel is always enclosed within a bag of anti-dusting material. Also the granules tend to become deliquescent in contact with liquid water.

Silica gel is also available in other forms. It can be compressed into tablet or pellet form for certain applications, but they are not much used in the Services because they are physically weak. The type of silica gel that is rapidly becoming the most widely used is a modified form in the shape of hard spheroidal beads. These beads are physically strong, do not dust or deliquesce, and have the added advantages of easier filling of desiccant containers and improved airflow in breathing desiccators. However, their capacity for moisture is about 5% less than the granular form (Figure 3).

Silica gel in both the granular and the beaded form is also available impregnated with cobalt chloride (Ref (6)). Neither is recommended for use in Service equipment (see section 4.1).

c. Molecular Sieves

Molecular sieves are synthetic crystalline zeolites in which the atoms are arranged in a definite pattern. Internally, the structure has many cavities inter-connected by smaller pores of a uniform size. These pores are only able to accept and pass to the cavities molecules of the same and smaller size, hence the name molecular sieve.

Molecular sieves are classified by pore diameter and types 4 Å and 5 Å* are used for water absorption. The material is available in powder, pellets, beads and granule form

The water vapour adsorption characteristics are very different from those of silica gel. As shown in Figure 4, molecular sieves can adsorb up to approximately 15% by weight of water before the relative humidity of the surrounding air increases significantly. Any further increase causes a large rise in relative humidity.

These characteristics enable molecular sieves to maintain very low dewpoints (-50°C for 10% by weight of adsorbed water). They also act very quickly so that they can effectively control relative humidity during very rapid cooling.

Reactivation is not normally attempted because it requires temperatures in excess of 250°C, together with a dry purge gas flow.

d. Activated Alumina

This material, which is little used nowadays, is a form of hydrated aluminium oxide. Its characteristics are generally similar to silica gel but its adsorptive capacity is lower (16% by weight at 50% RH). It is available in pellet or granule form and as well as being physically strong it can be reactivated (250°C) indefinitely without loss of efficiency. It was mainly used in packaging applications and in compressed air drying columns where its greater bulk for a given adsorptive capacity is not important.

*5 Å = 5 angstrom or 5×10^{-7} mm

e. Choice of Desiccant

For equipment applications there is only a choice between silica gel and molecular sieves. The choice is primarily decided by the maximum internal relative humidity that is considered appropriate for the equipment. If the usual 50% RH limit is applicable then silica gel is the only desiccant to consider. If a lower percentage relative humidity limit is applicable (eg 10% RH) then molecular sieves must be used. This immediately brings the possible disadvantage of a much shorter desiccator life than with silica gel because:

a. molecular sieves have a lower moisture capacity;

b. more moisture will enter the equipment because of the constant high water vapour pressure gradient across the equipment.

Therefore the use of molecular sieves should be very carefully considered. In fact, molecular sieves only show a real advantage at very low temperatures when condensation must be prevented (eg optically based systems) or where very rapid cooling can occur and fast adsorption is essential. It has been proposed that limiting the internal relative humidity to 10% maximum will improve reliability of equipments but as yet this is not proven.

3.4 DESICCATION TECHNIQUES

Desiccation means placing a quantity of desiccant inside a sealed equipment or package to absorb any moisture present and which penetrates the sealing barrier over a period of time.

A desiccator is the container for the desiccant. It may be of a type special to the equipment or of a standard design.

The desiccant may be contained in:

a. a dustproof bag or sachet secured against movement;

b. a perforated metal container secured to the inside of the equipment and removable only by opening up the equipment;

c. a perforated metal cylinder screwed and sealed into a side of the equipment container and thus easily replaceable without opening it; and

d. a perforated metal cylinder incorporating a breather inlet communicating with the exterior and screwed into a side of the equipment container as c.

Type (a) is mostly used in packaging applications, but where space is at a premium a small sachet is used within small equipments. Types (b) and (c) are known as "static desiccators" and type (d) as a "breathing desiccator". Standard types are covered by DEF STAN 44-2 (Ref (7)).

Static desiccators are used only in equipment built to a high sealing standard and strong enough to withstand the pressure changes to which it will be exposed in its working environment or in transit. In practice, there are small leaks in most such containers and changes of ambient temperature and pressure will force in some moisture. The magnitude of the pressure differential, especially in larger equipments dictates the structural stength of the equipment container, and hence weight and bulk.

Thus it is advantageous for structural and safety reasons to limit maximum air pressure differentials. This can be achieved by relief valves or by breather systems.

Pressure relief valves have disadvantages from the climatic protection viewpoint since they allow the input of moist air and require an air pressure differential in excess of 1 to 2 psi for reliable operation over a wide temperature range.

A breather system which equalises pressure differential via a tubular path having a large length to bore ratio operates at minimum pressure and under no airflow conditions offers a high impedance to water vapour inlet. This impedance is very high when the length to bore ratio exceeds 10:1, and so little water vapour flows under static (non breathing) conditions. When breathing, the gas mixture of air and water vapour traverses the tube.

The tubular path can be combined with the desiccator to form a breather-desiccator unit. This prevents a pressure build-up across the container and at the same time ensures that most of the incoming air passes through the desiccant which absorbs a proportion of the moisture.

As the container is not normally pressurised, it can be of light construction and sealing need not be of a high standard, since up to 20% parallel path leakages (see paragraph 3.5) can be tolerated without significantly affecting internal relative humidity.

Breathing desiccators have three disadvantages:

a. The equipment will not withstand immersion in water to a level above the height of the breathing desiccator inlet.

b. Where considerable internal self-generated heat is being dissipated, the heat transfer has to be made through the equipment case. At ground level this presents no more problems than arise from a sealed or pressurised construction, but at altitude the lower air density within the equipment makes internal convection less effective and so increases the cooling problem.

c. In airborne equipment a breathing desiccator will provide pressure relief under normal flight conditions, but it may not fully meet the requirements for rapid decompression arising under emergency conditions.

Static Desiccators

The standard range for use in service equipments is covered by Parts 2 and 4 of DEF STAN 44-2 (Ref (7)) as follows:

Part 2 - Desiccant Containers, Dehumidifier (Tubular Type)

These are small perforated metal cylinders (Desiccant capacity 2 to 8 grams) with a thread at one end. They are secured inside an equipment by screwing into a tapped hole. Internal relative humidity cannot be monitored unless the equipment is also fitted with an Indicator, Humidity Plug to DEF STAN 66-14 (Ref (8)). To change the desiccator necessitates opening the equipment. This type of desiccator can be assembled to an Indicator, Humidity Plug to DEF STAN 66-14 (Ref (8)) to create a small panel mounting type desiccator which can be easily replaced from outside when the humidity indicator paper (see section 4.1) shows this to be necessary.

Part 4 - Desiccant Containers, Dehumidifier (Sachet Type)

A range of sizes is available containing from 1 to 450 grams of desiccant. Whether used in an equipment or a package, the sachets must be secured to prevent movement.

Breathing Desiccators

These are covered by DEF STAN 44-2, Part 3 (Ref (7)). The tubular body (Figures 4 and 5) screws into a threaded hole in the equipment container and is sealed by an 'O' ring. Air enters via the annular inlet channel which is covered by a strip of PTFE coated wire mesh to prevent the ingress of rain, dust, insects, etc. The breather tube is connected at one end to the annular channel and its other end is covered with metal gauze filter to prevent particles of desiccant from blocking it. The condition of the desiccant is monitored by a small disc of cobalt chloride humidity indicator paper in contact with it behind the clear glass window.

Three types of breathing desiccator are in use. The style XDB (Figure 5a) and style IDB (Figure 5b) are identical except that the former incorporates a rain shield and is intended for use in equipments which will be fully exposed to the elements. In both styles the desiccant is contained within a porous, anti-dusting paper or plastic tube and is renewable via the filler plug. The cut-outs in the body enable the desiccant to mop up any moisture which enters the equipment through leaks or by diffusion through permeable materials.

The style DBT is an early design which incorporates a second breather tube between the desiccant and the interior of the equipment. It has many disadvantages compared with the other two types and is not recommended for use in new equipments.

Breathing desiccators are available in a range of sizes to suit equipments of different internal volumes. Details are given in DEF STAN 44-2, Part 3 (Ref (7)). It is most important that the size of desiccator is decided early in the design process so that adequate space can be provided for it in a position where it is readily viewable and accessible in Service. This objective has not been met in some current equipment in which 4 or more small desiccators are fitted to a single small unit, many of them not accessible without disconnecting the equipment and removing the unit. In practice this often means that desiccators are not changed when they should be, with a potentially damaging effect on equipment reliability.

Desiccator Life

The size of desiccator recommended for a given equipment volume is shown in the Tables of DEF STAN 44-2, Parts 2, 3 and 4 (Ref (7)). In general, a life of 3-9 months can be expected in the worst environments (fully exposed locations) and longer in less severe conditions, eg semi-protected locations and storage. However, selection according to this Table does not automatically result in a guaranteed life for the desiccator. The actual life depends on the leak rate of the equipment, the equipment environment and the equipment operational pattern.

Also an equipment can hold an amount of adsorbed moisture that is large in comparison with the sizes of desiccator in the Tables of DEF STAN 44-2, (Ref (7)). During some experimental work (Ref (9)) the adsorbed moisture in a number of equipments was determined and compared with the capacity of the desiccator fitted. The comparison is shown in Table 1.

In general, therefore, a desiccator selected for an equipment of a given volume should always be at least the minimum size recommended. In certain circumstances, such as when an equipment will be functioning for the greater part of its life or when the required life must be long between replacements, it would be preferable to fit either more than one unit of the recommended size, or as large a unit as can be accommodated.

A further point affecting desiccator life is that equipments fitted with breather valves can, depending on the pressure cycling pattern have a larger than normal moisture input.

The earlier series of equipment desiccators were changed when life was expired and could be disposed of and replaced by a new unit, or be reactivated by heat under controlled conditions. Because of reactivation

disadvantages (see paragraph 4.2) newer designs are rechargeable with fresh desiccant, and a range of prepacked desiccant changes is listed in DEF 44-2.

RF Screening

On some equipments it is necessary to protect against RF radiation. Special desiccators are available with a gauze screen across the sighting window behind the humidity indicator together with good earth continuity surfaces where the desiccator is to bond with the equipment.

Colour Coding

To enable the contents or type of desiccator to be identified, the body is usually colour coded. The basic colour code is as follows:

Silica gel (granular)	Olive drab grey or black
Silica gel (beaded)	Green
Beaded Molecular Sieves 4 A	Blue
RF Screened	Lime green plus desiccant colour.

Alternative Approaches

In certain instances, a dry equipment interior is maintained not by desiccant but a flow of dry air or gas. The flow can be on a recirculation or total loss basis, and this method is mainly applicable to installations in cabins or buildings, or to specialised airborne equipment in conjunction with pressurisation.

Pressurisation with dry nitrogen is occasionally used for airborne equipment units and for exposed waveguide runs on ground equipment - mainly for electrical reasons. This does not eliminate diffusion of water vapour inwards which is solely govered by the water vapour pressure gradient, but it does prevent liquid water from being sucked in through any leakage paths. Additionally, to maintain a postive internal pressure over a long period demands the highest standard of sealing, so that diffusion effects will often be reduced. Although not strictly relevant, the common use of heaters with partially sealed equipment helps to maintain a dry interior by preventing the air falling below dew-point.

3.5 SEALING STANDARDS

a. Equipments not fitted with breather desiccators

The sealing standard must be set so that it provides adequate climatic protection, be readily achievable in production and during maintenance and easily checked.

The standard specified should form part of the equipment specification. Values used can vary widely and are often empirical or arbitrarily chosen, with consequent problems.

In the experience of the author, it is considered that a minimum leakage rate of 120 cc/minute/m^3 of equipment volume for equipment fully

exposed in operation and a figure of 400 cc/min/m^3 of equipment volume for equipment operated exposed, but with some protection against water and rain is adequate. The test is made at 2.5 psig, and the equivalent pressure drop figures of 0.125 and 0.4 psi per hour are detectable on a simple gauge during a 15 minute test period without significant problems from temperature change.

Leak detection is sometimes required for this type of equipment and the many methods available range from the use of soap solution and bubbles to electronic detection of tracer gases.

With this type of equipment, the assumption that airtight means sealed is justified as a test method but does not guarantee a standard of climatic protection. This can only be obtained by a correct choice of materials and design to minimise water vapour diffusion effects. Diffusion through sealing materials and gaskets needs to be checked at the design and proving stage and if the adequacy of the design is demonstrated by climatic testing it is unlikely to cause problems in Service even after resealing if pressurisation tests are satisfactory.

b. Equipments fitted with breather desiccators

The problems of bulk and weight arising with fully sealed equipments in the medium and larger sizes can be overcome by the use of breather desiccators, enabling light weight construction and a low standard of sealing.

It has been shown (Ref (11)) that moderate leak rates, in most circumstances, do not significantly shorten the life of the breather desiccator.

The leak rates in this instance are determined by measuring the airflow through all the leaks at a low pressure -2.54 cm wg. (As all these leaks are in parallel with the breather desiccator, the term "parallel path leakages" is often used). The recommended tests procedure is given in Ref (11).

The permissible leak rate is related to volume and the work mentioned above (Ref (11)) established that the maximum leak rate for equipments in fully exposed situations is 0.0025 m^3/min per unit volume (m^3). 'Volume' in this context is that calculated from overall internal dimensions. Where an equipment will never be fully exposed, a relaxation to a maximum of 0.005 m^3/min per unit volume (m^3) may be made by agreement with the Approving Authority in a situation where major costs are involved in meeting the normal standard.

One possible problem that could arise with these relatively high leak rates is that the leaks could consist of a large single hole rather than a large number of small holes or leakage paths. The single hole could cause trouble as being large enought for free water on the surface to enter as a result of capillary action, or be drawn in even by a low pressure differential. This possible problem can be mitigrated by equipment designs which shed free water or by the application of a water repellent treatment to gaskets and mating surfaces, or in practice if the hole location is obvious, remedial action taken. Tests have shown (Ref (11)) that the application of fluoropolymer based water

repellents reduce surface tension and effectively prevent water ingress by capillary action. The water repellent should be applied to the mating parts of the seal before assembly of the equipment, and generally around the seal after assembly. Re-treatment will be necessary after long exposure periods (say 6 months) and after opening an equipment for maintenance or repair.

The tests showed that two water repellents were significantly better than others. They were:

i. Xylan - fluoropolymer based; and

ii. Molykote - polytetrafluorethylene based.

Both are available as an aerosol spray.

3.6 BARRIER MATERIALS

Most of the non-metallic materials used for climatic protection are water vapour permeable to some degree. The problem has been considered in equipment packaging for many years, but with current use of plastics materials for equipment container designs it has assumed some importance here as well. Also, gaskets and sealing materials invariably use rubbers, plastics and papers which are all permeable and allow water vapour diffusion.

In general terms, the rate at which water vapour diffuses through a material is directly proportional to the vapour pressure difference and inversely proportional to the thickness. Absorption effects with hygroscopic materials and temperature cause some modification to this statement.

In packaging for long term protection, polyethylene sheet is generally used, sealed into a continuous barrier around an equipment. Polyethylene is a good barrier material (0.5 mm thick polyethylene has a permeability of 1 g/m^2 d in tropical conditions). Laminates incorporating a metal layer (usually aluminium foil) are occasionally used instead of polythene and the permeability of such materials can be 1/10 or 1/100 that of polythene.

For equipment construction, the plastic materials have to be much thicker for strength reasons, but are very often not very good barriers. Small containers may be made from moulded sheet materials, such as acrylonitrile butadiene styrene (ABS), glass reinforced polyester (GRP) or polythene. In larger containers greater stiffness is required and these are often moulded from sandwich materials consisting of a core of light weight plastic foam, plastic or metal honeycomb or balsawood, with skins on either side of GRP or other plastic sheet.

Some Water Vapour Transmission Rate (WVTR) figures for typical equipment construction materials are given in Table 2. The sandwich materials can be improved by incorporating a laminate of aluminium foil or low permeability plastic film on the inside surface.

During some work on a computer simulation of the mechanism of permeation through composite materials (Ref (12)), it was found that a good estimate of the overall WVTR of a composite material is obtained from simply summing the reciprocals of the individual WVTR values. Thus for a sandwich material with skins of 2 g/m^2 d permeability and a core of 50 g/m^2 d permeability the

overall WVTR (P_c) would be:

$$\tfrac{1}{2} + \frac{1}{50} + \tfrac{1}{2} = \frac{1}{P_c}$$

$$0.5 + 0.02 + 0.5 = \frac{1}{P_c}$$

$$\therefore P_c = 0.98 \text{ g/m}^2\text{d}$$

It is interesting to look at the effect of different permeability core materials on a composite material. Figure 8 shows the effect on composite WVTR for a wide range of core permeability values. This clearly shows the WVTR of the core of a sandwich-type material is relatively unimportant and so structural requirements should be the prime consideration. However, the use of a non-hygroscopic core material (eg closed cell foam) will minimise the effect of damage to the outer skin of a sandwich-type material.

In practice, most problems with equipments made from any type of material are associated with the sealing of lids, access covers, etc. Gaskets and seals for equipments usually rely on a non-metallic resilient material in conjunction with mechanical constraints, eg flat gaskets, bonded seals, 'O'-ring seals, trough and tongue seals. Although all the resilient seal materials are permeable to some degree, when used in a good mechanical design a very low WVTR can be achieved. Measurements (Ref (13)) have shown that the WVTRs of a wide range of materials and seal types are of the order of 5×10^{-3} g/d per metre length of seal. Actual values obtained for flat gaskets and 'O'-rings are given in Table 2.

These values could be considered sufficiently low to be insignificant when compared with other inputs, but in practice, higher figures are applicable because of design limitations imposed by weight considerations, flexing of structures, clamping and assembly problems and deterioration with time.

4 ALLIED ASPECTS

4.1 HUMIDITY INDICATORS

a. General

An important facet of climatic protection is humidity indication. This is needed to monitor internal conditions within an equipment and show when a given level of relative humidity has been reached or exceeded. The generally accepted 'safe' level for the interior of an equipment is 50% RH (see section 2) and using silica gel as a desiccant an indicator that shows 'unsafe' at about 50% RH is required. Desiccators filled with molecular sieves (see section 3.3) may need an indicator that shows 'unsafe' at a much lower level - approximately 10% RH. Indicators are infrequently used in undesiccated containers but are really of little value as the relative humidity may vary with temperature, and the indication of an unsafe level will depend largely upon the temperature at which the indicator is viewed.

For a desiccated enclosure, the relative humidity will remain

substantially constant with temperature change provided the desiccant is allowed time to reach a new equilibrium level. If the indicator is separate from the desiccant an indicator will respond better to internal conditions which is the requirement.

b. Humidity indicator papers

The most widely used indicators are based on colour change using an absorbent paper impregnated with cobalt chloride or other cobalt salts which changes from blue to pink in the presence of moisture.

The relatively crude indication of the widely used cobalt chloride impregnated paper, with a nominal indication level of 50% is not ideal in that a definite blue is only seen up to say 30% RH and a definite pink appears around 60%. In between, an imprecise greyish white indication is given. This 25% RH wideband of imprecision is the area of most importance in climatic protection, covering safe to unsafe conditions. Also, with the basic cobalt cloride paper, the colours are not very intense and so can be misread under unfavourable lighting conditions.

A conscientious technician would change a desiccator or take other action at the end of the blue indication. However, with silica gel desiccant, the desiccator would have considerable unexpired capacity which, expressed in time terms, because of the decreasing rate of pick-up with time can be of the order of 2-3 times that elapsed.

Thus a precise colour indication would have considerable benefits and reduced maintenance costs. See Figure 7.

A programme of work was undertaken (Ref (14)) to develop a more satisfactory humidity indicator paper for use in desiccation devices. The improved indicator paper, which had added chemicals and dyes and a specified paper substrate shows a narrower range of humidity for the pink to blue change centred on 50% RH, and most importantly always displays a definite colour which virtually eliminates any misinterpretation. The improved paper has undergone Service trials with the RAF (Ref (15) and (16)) and has been shown to result in a desiccator life approximately three times longer that than achieved with the current indicator paper fitted to desiccators.

A specification controlling the characteristics of the improved paper has been raised so that it can go into general use. The specification consists of two separate parts - one controlling the paper substrate - MQAD Specification TS 10232 Base Material for Paper, Humidity indicator, Colour intensified, and the other the cobalt chloride formulation and acceptance testing - MQAD/CFU Specification CPU/CON 203-1 Paper Humidity Indicator (Colour Intensified) Ref (23).

As a direct result of the Service trials mentioned above, another low reading paper based on 10-15% RH was developed for use with molecular sieve desiccant now increasingly used in GW systems.

c. Split level indication

A further refinement in the indication available from indicator papers is possible by using side by side two papers set for different RH levels - say 15-20% apart. If the lower reading paper is blue, then the relative humidity is below its lower limit. If it is pink but the higher reading paper is blue then there is an indication that the RH is at the lower limit of the high reading paper.

This information enables a more accurate assessment of the remaining life of the desiccator and thus whether a change of desiccant is absolutely necessary or whether it can be deferred until the next service.

If both papers are pink, the equipment should be carefully examined as this is likely due to gross water leakage into the equipment.

The form in which split level indication is to be introduced into limited Service use is of two adjoining semi-circles of paper as seen through the desiccator or humidity plug window. The main advantage of the dual indication is likely to be with molecular sieve desiccant where accurate low reading ability is important. Obviously the use of colour intensified papers is recommended to give greatly enhanced readability and performance to the two papers.

d. Cobalt chloride impregnated desiccant

Silica gel and other desiccants can be impregnated with cobalt chloride and exhibit colour change as moisture is absorbed. The commercially available material changes colour at a variable RH level which depends on the desiccant manufacture and impregnation procedure, and is generally below 20%. Ref (16)). So indicating gel is not recommended for use with equipments, at best it being a pointer to the state of the desiccant. Thus its main use is to give a visual check on the condition of bulk desiccant supplies.

e. Electrical humidity sensors and indication

Uses can be envisaged for the remote reading or indication of the humidity conditions within sealed equipments. The uses include areas where a visual check through sight windows is not possible, ie in large GW containers and packages, within sealed sub-assemblies, inaccessible or stacked equipments in store. Also for central point monitoring in store houses and for activating alarms when unsafe conditions arise and, most importantly in conjunction with automatic test equipment. Another application is for measurement of RH in critical areas - high power waveguides and lasers and radio active items.

Electrical humidity sensors and indicators are available in a variety of types and operating principles.

A number of conditions must be met for a system monitoring conditions within equipments, operational and in store, and this severely limits the choice of device.

Any system consists of two parts - the sensor and the read-out. The sensor output interfaces with the read-out at the container wall. In any Service application, with a given humidity indicating system, any sensor must be compatible with any read-out device which means that sensor characteristics must be closely controlled, and the interconnection and wiring system must be non-critical and preferably two-wire. Possible low-cost sensors will operate on resistive or capacitive change with humidity, other approaches to date being ruled out by cost and complexity.

Capacitance change sensors are, unless integrally fitted with complex circuitry and active devices which also require more than two wires, very much affected by the interconnection system.

Limited use may be possible with devices of high intrinsic capacity with padding capacitance. Also, most simple capacitance sensors based on porous metal oxides are contamination prone.

Resistive change sensors fall into two types - those which operate on change in bulk resistivity and those which operate on resistive change of a surface film. The resistance range must lie within the limits of too high a resistance which raises insulation problems and too low which can cause interconnection problems. Polarisation effects can arise from DC operation while AC operated devices will exhibit a complex impedance.

For any of the above principles, the sensor must be stable over a wide temperature range for a minimum period of say five years and the cost must be acceptable for wide spread adoption. Also, the device must fail safe or be easily checkable for integrity otherwise open circuit may be misread as high impedance.

Linearity of the humidity analogue is desirable for measurement purposes, but can be achieved electronically for some devices.

For indication purposes, linearity is not so important, in fact, a sudden change in characteristics at the RH level of interest is exploitable. Many types of resistive sensor tend to a logarithmic law and this is obviously useful.

Over the period covered by this memo, RSRE Reliability and Environmental Engineering section have maintained an interest in low cost sensors for 'in equipment' use, and have examined commercial devices and principles which could meet the Service requirement. This is specified in outline in Ref (18).

The assessment of any sensor can be very protracted because of the need to examine stability of characteristic under real-time conditions.

It must be said that success had been very limited, especially in the below 30% RH region. Very few sensors are stable over a 1 year period, some are irreversibly damaged by high humidity, and many of the electronic type based on thick or thin film devices were found to be not consistently manufacturable. Reports of some of the work carried out by Giltspur Packaging R&D Section under MOD(PE) contract are contained in Ref (17),(24),(25),(26).

The most promising future approaches, not in any merit order are considered to be:

i. The relatively unsophisticated 'salt tape' device using the resistive change of a sodium chloride impregnated cotton tape. A Service approved sensor of this type has been available for some time for packaging applications (Ref (20)). It is too large and unsuitable in format for equipment applications, and to overcome this, an improved and miniaturised version has been developed under contract with EPS (R&D) Ltd. It has been demonstrated that consistent sensors can be produced and that one of the shortcomings of this type of sensor - damage arising from transient high humidity (> 80% RH) can be limited by enclosing the sensor within a permeable barrier which slows response time to a period much longer than any transient RH change.

ii. Thick film capacitive sensor. This uses a thick film paste incorporating aluminium oxide in the form of a porous humidity sensitive glass as a dielectric and gives a basic capacitance of hundreds of picofarads and a change with RH of about a quarter. It has not yet proved possible to manufacture sensors which repeat the performance of the early batches made at Brighton Polytechnic (Ref (24)).

iii. Thin film polymer dielectric sensors. This is a small capacitor with a polymer dielectric which swells with humidity. The basic capacitance is a few picofarads with an RH change of parts of a picofarad, so electronics are needed at the sensor to translate this change into a more usable analogue. The commerical version of this sensor (Vaisala system) is excellent and has been used as a tool in most of the sensor evaluation work. It is expensive and bulky and a simple and cheaper version is sought.

iv. It should be possible to improve the well established Dunmore (meteorological) and Phys-Chem (instrumentation) resistive sensors to improve long term stability and engineer out its habit of going open circuit after extended exposure at the low humidity which occurs in desiccated equipments.

4.2 DRYING OUT PROCEDURES

In earlier sections the problem of the penetration of moisture into nominally sealed equipments and how to deal with it has been discussed. However, there is another facet to this problem which needs consideration.

When electronic equipments are opened for repair or maintenance in a humid environment they can quickly adsorb quantities of moisture that are large in relation to the moisture capacity of the desiccator fitted to them (see Figure 8.3 and Ref (9)). The actual amount of moisture adsorbed by an equipment depends upon its type of construction and its volume. Chassis type construction adsorbs less than printed circuit board type construction, the amount being related mainly to the surface area of the internal hardware. Yardstick figures are 16 grams per cubic foot of equipment volume for PCB equipments and half this for chassis type equipment.

Figure 8 shows the relationship between moisture pick-up and equipment volume (calculated from overall internal dimensions only) for both the older chassis type and current PCB type equipments. These graphs were obtained from measurements on a variety of equipments exposed for 3 hours to an environment of 30°C and 70% RH. Longer periods of exposure were found not to increase the amount of adsorbed moisture significantly, so the graphs can be assumed to represent worst case conditions, and in much servicing or repair work far less moisture will be adsorbed (Ref (9)).

The adsorbtion problem can also arise at the production stage, the internal hardware and sub-assemblies often being exposed to a damp ambient for an extended period before assembly.

If an equipment is resealed after opening in a humid environment, or sealed during production and no attempt is made to remove some of the adsorbed moisture, probably the only obvious effect will be that the life of the first desiccator fitted will be very short, and the life of the next two or three desiccators will also be reduced. However, although the relative humidity will tend to be controlled during this period as long as desiccators are changed at the correct time, it is possible that the large quantities of adsorbed moisture could have a detrimental effect on electronic circuitry and hence reliability.

Common sense would dictate that some at least, of the adsorbed moisture should be removed as soon as possible after exposure to a humid environment.

In fact, it is Service practice whenever practicable to subject any dismantled equipments to some drying procedure either before or after finally resealing. Drying procedures in current use include:

a. heating in a oven;

b. purging with hot dry air;

c. pressure/vacuum cycling;

d. desiccation.

The procedure used is often dictated by the particular equipment to be dried out and the availability of apparatus, but all will work with varying degrees of efficiency.

Each procedure has its merits and demerits:

<u>Oven heating</u> is a basic approach for use with equipment out of its case and before sealing up. It can use improvised apparatus but the oven must be ventilated, fitted with accurate temperature control and allow adequate free space around the equipment for air circulation. The maximum temperature should not exceed +60°C, this being the upper limit for a number of components and materials. It is best suited for processing a number of units concurrently, where the units can be taken to the oven.

<u>Hot air purging</u> in which a flow of dry and preferably hot air is blown into the equipment case through a suitable port and is thus applicable to equipment resealed in its case. Also, the air supply pipe can be taken to equipments in convenient and inaccessible locations. The procedure can be single or double port.

Single port purging is carried out via a suitable resealable hole with annular clearance around the hot air supply pipe and the purge air is exhausted through the annular space.

Double port purging uses two holes, one inlet and one outlet. The exhausted air is recirculated back into the dryer unit. Either method requires a good circulation path through the equipment interior for satisfactory action. This is more easily achieved with two ports at extreme ends of the case, and also, recirculation of the exhaust greatly reduces the heat and dry air load on the dryer unit. Temperature limitations are +60°C maximum at the supply pipe exit.

Pressure/Vacuum cycling - This method requires special equipment, is recirculatory but consists essentially of pressurising the equipment through a sealing adaptor with hot dry air to a positive pressure of several pounds per square inch, holding for a few minutes, then evacuating the equipment to several pounds per square inch negative and holding for a few minutes then repeating the cycle as required. It has great advantage for equipments with relatively inaccessible confined spaces such as optical and laser equipments and has no great advantage for electronic equipments. The efficiency of the process is a function of the internal volume of the equipment.

Desiccation - This approach is confined to using a series of desiccators to dry out the newly sealed equipment. The method is sound, but has a big disadvantage in the time, measured in days to achieve a suitable dryness.

The first three methods can remove the bulk of the water present in a period of one or two hours, method 2 and especially method 3 can usually only deal with one equipment at a time.

Some of the recirculatory dryers have a humidity sensor to measure the dryness of the exhausted air and use this to terminate the drying cycle at a predetermined level. This figure does not correspond to the RH level which will pertain soon after closing up the equipment unit. The RH level will invariably rise to equilibrate with the moisture still out gassing from the surfaces and components.

Comparative tests show (Ref (9)) that purging with hot dry gas at 50-60°C using the double-port-closed-loop system is the most effective method, closely followed by oven heating. However, purging requires special test equipment, whereas oven drying is easily carried out in the field, if necessary in an improvised oven. Water is given up by equipments much less readily than it is adsorbed and 2 to 3 hours is required to remove about half the adsorbed water using either of the most effective procedures. The remaining water is not readily given up and to completely dry out an equipment would take weeks. However, complete dryness is not necessary and could even lead to problems due to shinkage, cracking, etc. The two most effective drying procedures will restore normal conditions with a minimum of time and effort.

There are a number of drying-out equipments now available for Service use which utilise the foregoing thinking. Some are dedicated to particular systems, and others are of a general purpose nature with multiple facilities.

These can provide a supply of hot-dry purge air, operate in the pressure/vacuum mode, function as a portable drying oven, and carry out reactivation of tubular desiccants.

4.3 REACTIVATION AND RECHARGING OF DESICCATORS

A major change in desiccation policy has been the acceptance of desiccator recharging rather than reactivation of spent units using silica gel desiccant.

It is interesting to review the background.

For many years it has been the policy to reactivate the desiccators by heating either in ventilated ovens or in special heater units at +140°C.

Experience in the field and workshops of poor desiccator performance and life gave desiccation as a technique aiding reliability a bad name. Investigation by several organisations showed poor reactivation procedures together with imperfect understanding of the amount of moisture present in equipments not adequately dried out after opening up to be the causes of the apparent poor performance.

Reactivation is an acceptable process under controlled conditions but in practice:

a. Repeated reactivation lowers the adsorbtion capacity and makes it physically break up and dirty.

b. The desiccant can lose capacity if it becomes contaminated by adsorbing gases such as ammonia and refrigerants and organic vapours arising from paints and plastics and also dust and grease.

c. Overheating causes deterioration of desiccant by reducing the effective surface area.

d. Too low a temperature or insufficient ventilation to carry away the driven-off moisture reduces reactivation efficiency.

e. There is a strong possibility that the indicator paper - if integral with the desiccator or is not removed beforehand can deteriorate as a result of the heat.

f. Problems have arisen with sachets made from plastic coated fibre fabric. The heat can fuse the plastic and make the fabric almost impermeable to water vapour. Also the sachet heat sealing can be damaged.

So since it is not possible to guarantee correct reactivation under service conditions and, more importantly the previous history of the desiccant is unlikely to be known, there is a very strong case for the use of new desiccant. This fact, combined with increasing use of molecular sieve desiccant which is not easily reactivated makes a policy of recharging most desirable.

4.4 LOGISTIC CONSIDERATIONS

The logistics and economics of a recharging policy need close consideration.

Present Breather-desiccator units are fitted with a filling plug and so spent desiccant can be emptied out and refilled with fresh desiccant.

Standard tubular static units to DEF STAN 44-2 cannot be refilled and so a new version to the same outline with a filling plug is being introduced.

The small quantities of desiccant required for refilling can be taken from a bulk container. In practice this causes problems because the bulk container must be resealed after use and must not remain open for any length of time if the condition of the desiccant and its shelf life are to be maintained.

For field use, individual prepacked changes of desiccant are more practicable and a limited range of the popular sizes is available at present.

Desiccator units provided as spares, both static and breather must be provided with a protective pack in the form of a well sealed aluminium screw-top can, to guarantee a nominal 5 years shelf life. The cost of this packaging is a large part of the cost of a desiccator.

Similarly, prepacked charges need protective packaging for the 5 years shelf life. The cost of the packaging is many times greater than the cost of the refill, and is comparable with the cost of the packaging for a complete desiccator unit.

The provisioning and stores organisation thus has to cope with complete desiccator units in a range of sizes each with several alternative fillings, a range of prepacked refills and supplies of bulk desiccant - all limited shelf life items. Some considerable rationalisation in this area will be called for. A possible approach will be to supply empty desiccator units only plus the required filling as a separate item.

4.5 MEASUREMENT TECHNIQUES

To facilitate development and investigation in the foregoing areas of climatic protection, accurate, versatile and rapid moisture measuring instruments are needed. Up to a few years ago no satisfactory instruments were available for this type of work and an extramural work programme initiated and monitored by RSRE resulted in the development of the Sweep Gas Electrolytic Hygrometer techniques described below. Developed to measure low water vapour transmission rates (WVTR) of the newer plastics films and constructional plastics (Ref (21)), its use has been extended to provide a simple sensor system for accurately measuring the humidity in sealed containers (Ref (22)). This has greatly facilitated the evaluation of desiccation and drying out techniques.

The basic principle of the Sweep Gas Electrolytic Hygrometer technique is that the water vapour to be measured is carried in a dry nitrogen gas flow to an electrolytic cell which electrolyses the water vapour to hydrogen and oxygen. The electrolysis current is directly related by Faraday's Law of Electrolysis to the mass flow of water vapour into the cell, and so the measurement method is an absolute one. The method is sensitive enough to measure 1 ppm and can determine water quantities in the order of 0.1 μg.

The system to measure WVTR of films sheet materials and rigid boards etc is shown in Figure 9.

The temperature controlled oven contains a Diffusion Cell which is divided into upper (dry) and lower (wet) chambers by the test specimen, the lower chamber containing water or a salt solution. Dry nitrogen is passed continuously through the upper chamber, and the water vapour diffusing through the test specimen is swept away to the measuring Electrolytic Cell. With a test specimen area of 50 cm^2, a WVTR of 1 g/m^2 d corresponds to 47 ppm at any temperature.

The system for measuring relative humidity is shown in Figure 9. The humidity sensor is a short length of silicone rubber tubing of known permeability characteristics or calibration. The amount of water vapour permeating into the tube is determined by the ambient temperature and relative humidity and it is continuously swept away to an electrolytic cell. If the container under test is not in a temperature controlled environment, a temperature sensor must be fitted adjacent to the humidity sensor. The accuracy of the system is ± 2% RH, and in normal circumstances the very small quantities of water vapour removed from the atmosphere to make a measurement are insignificant.

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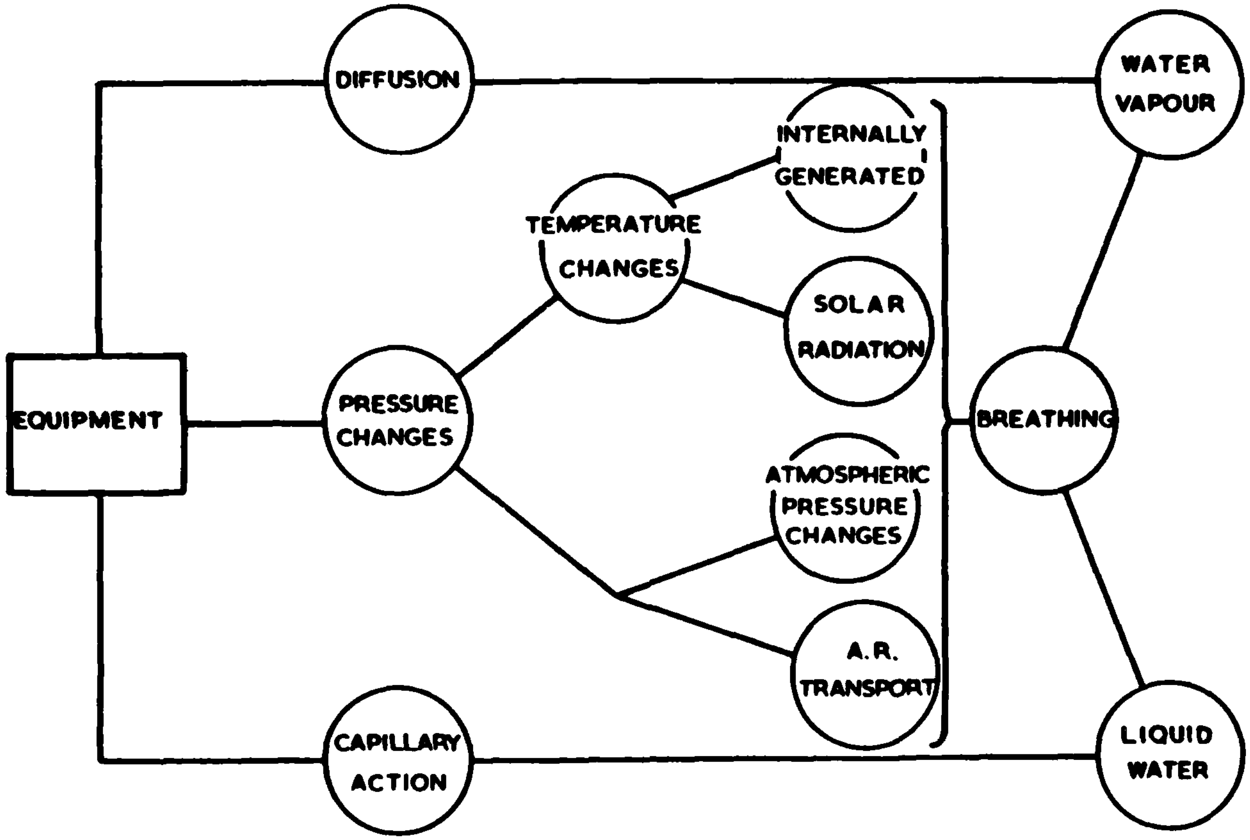


FIG. 1. MECHANISMS OF MOISTURE ENTRY

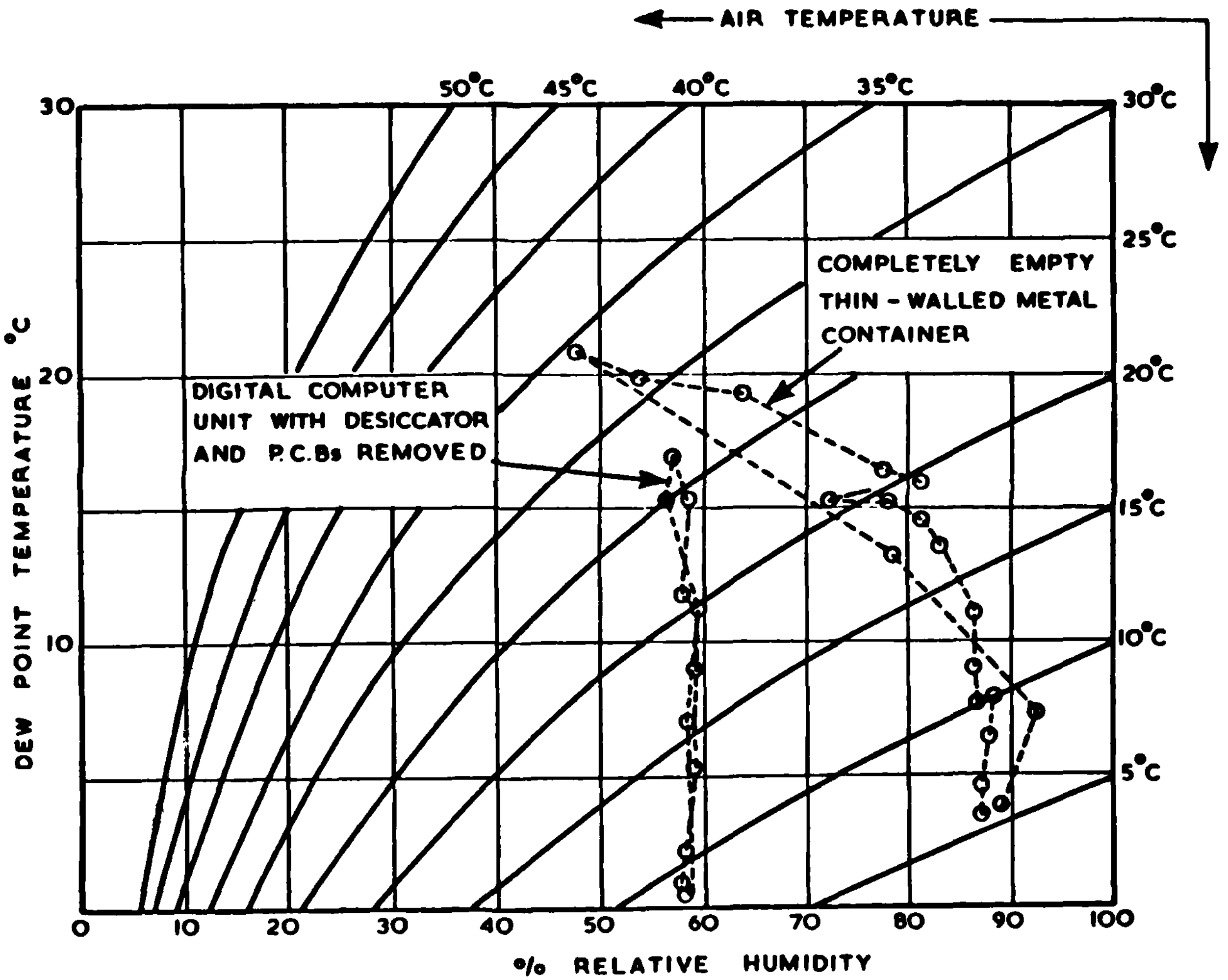


FIG. 2. LAG - LOOPS FOR A COMPLETELY EMPTY METAL CONTAINER AND A NOMINALLY EMPTY EQUIPMENT

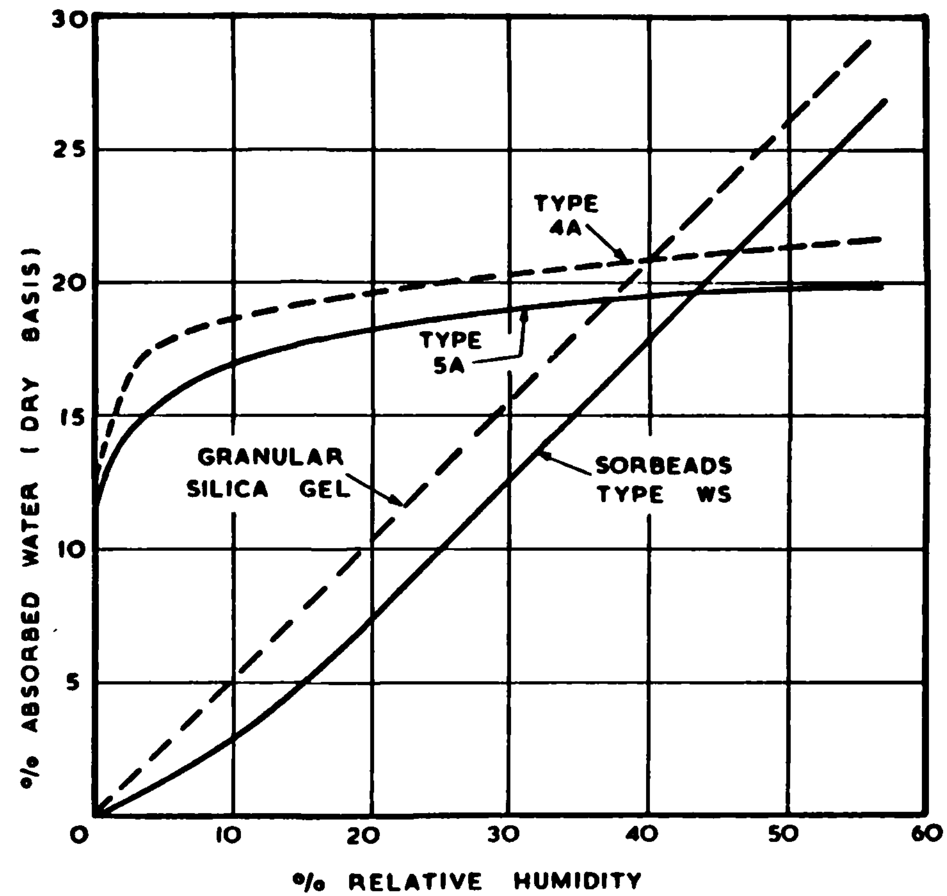


FIG. 3 ABSORPTION CHARACTERISTICS OF SILICA - GEL AND MOLECULAR SIEVE DESSICANTS AT 25°C

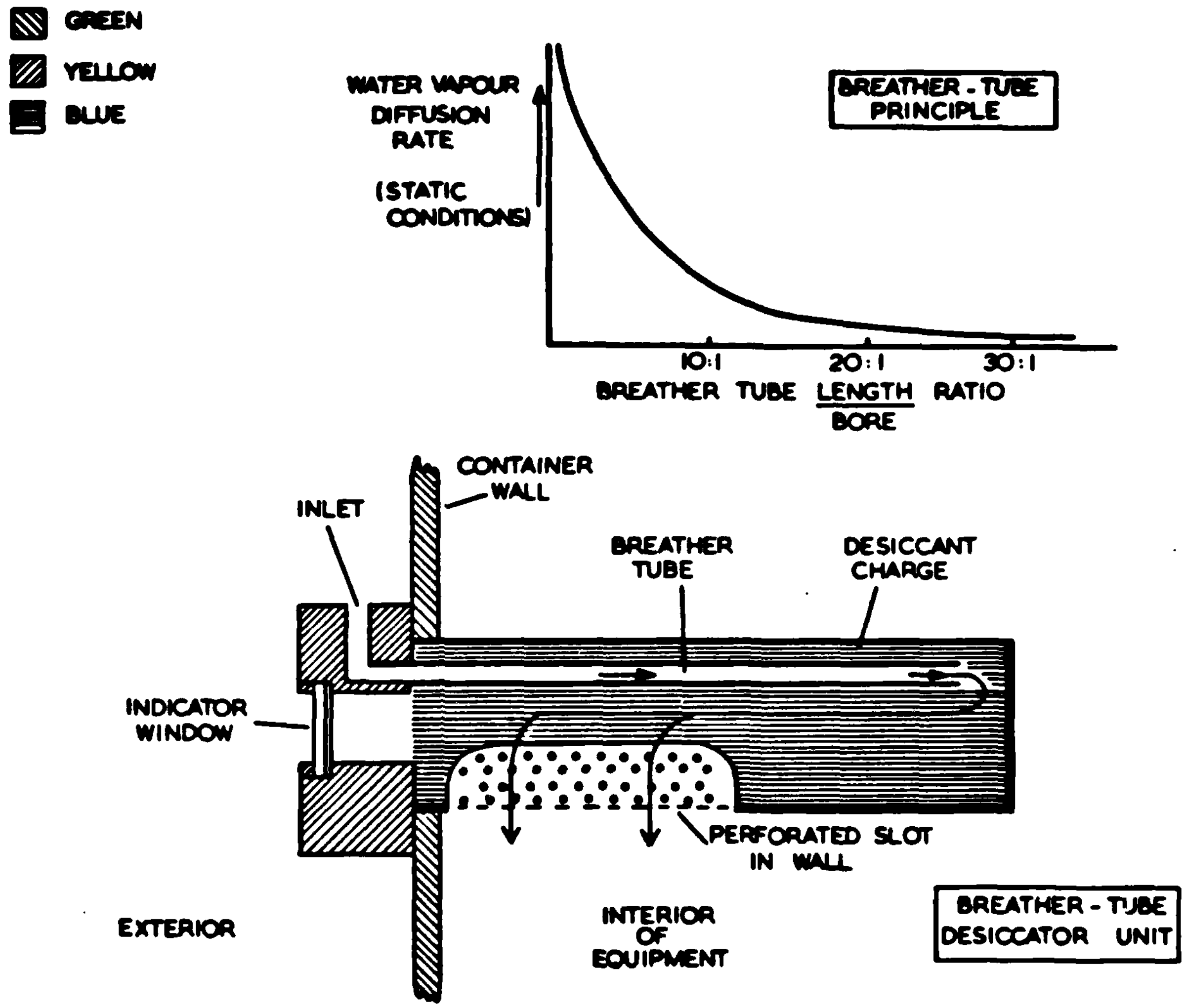
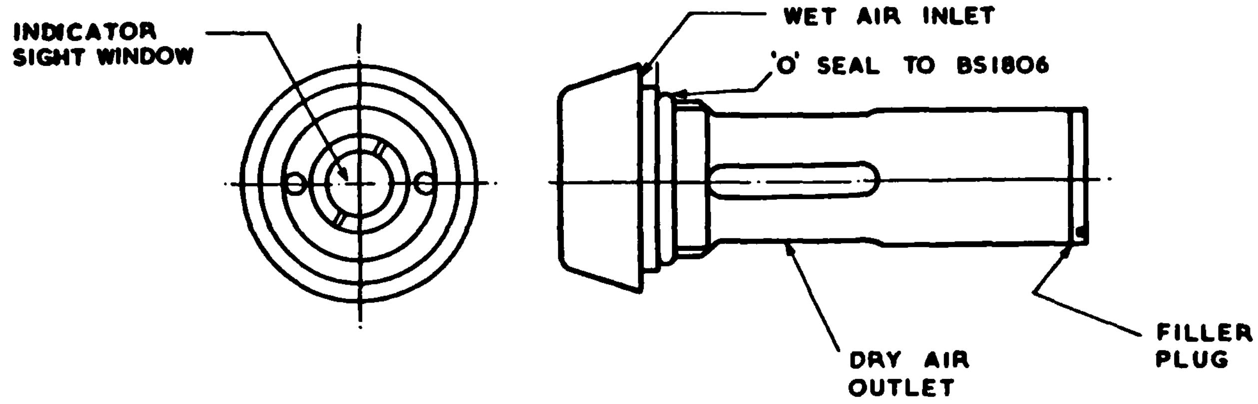


FIG. 4

BREATHER-TUBE DESICCATION



XDB TYPE BREATHER DESICCATOR

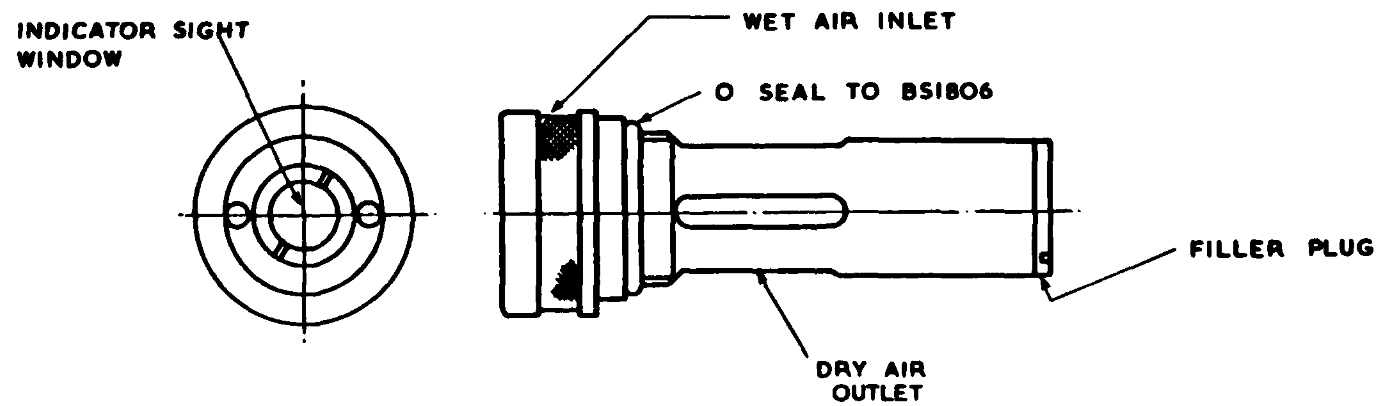


FIG. 5. IDB TYPE BREATHER DESICCATOR

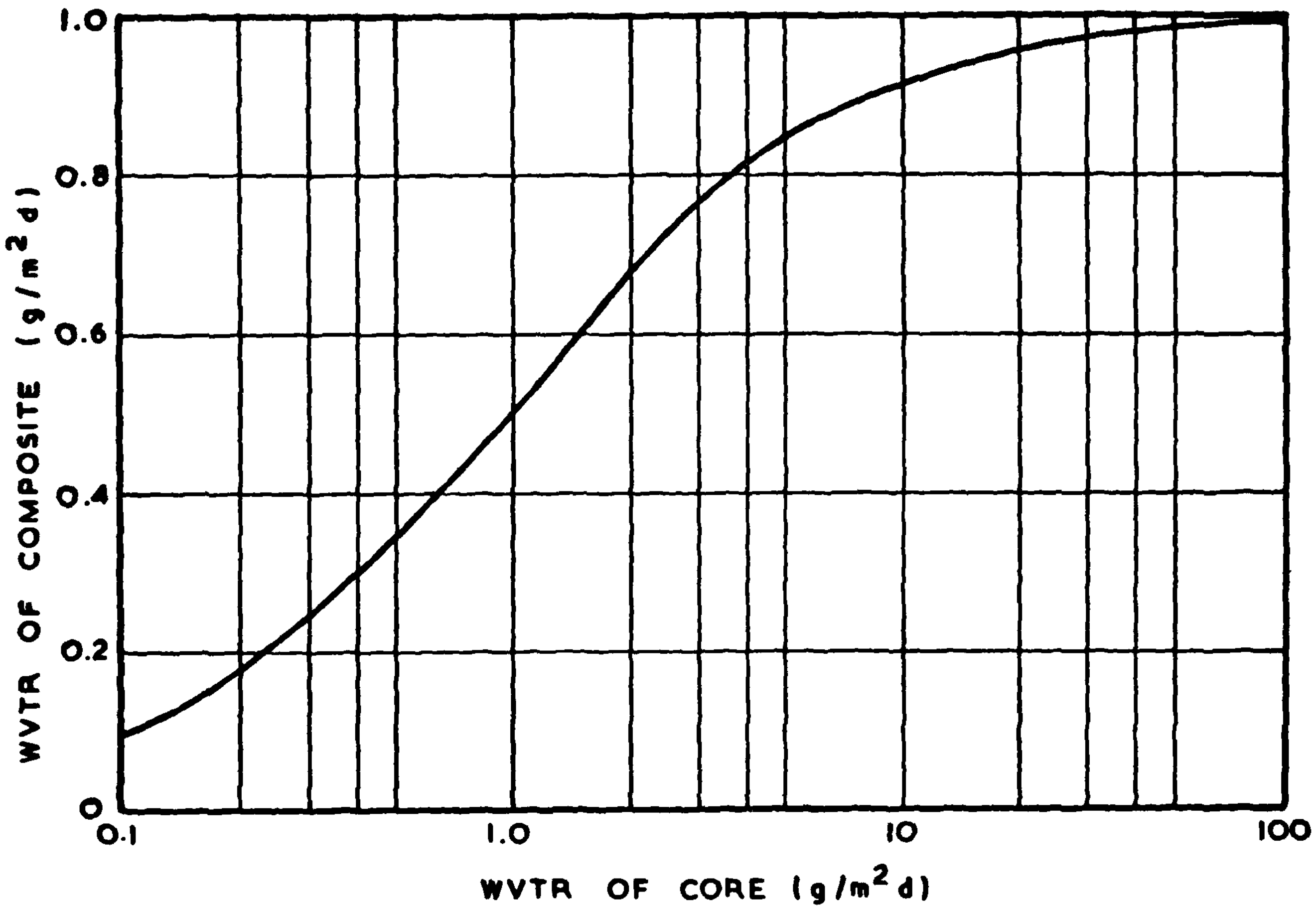


FIG. 6. EFFECT OF VARIOUS CORE WVTR VALUES ON OVERALL COMPOSITE WVTR

WVTR OF SKINS $2 g/m^2 d$

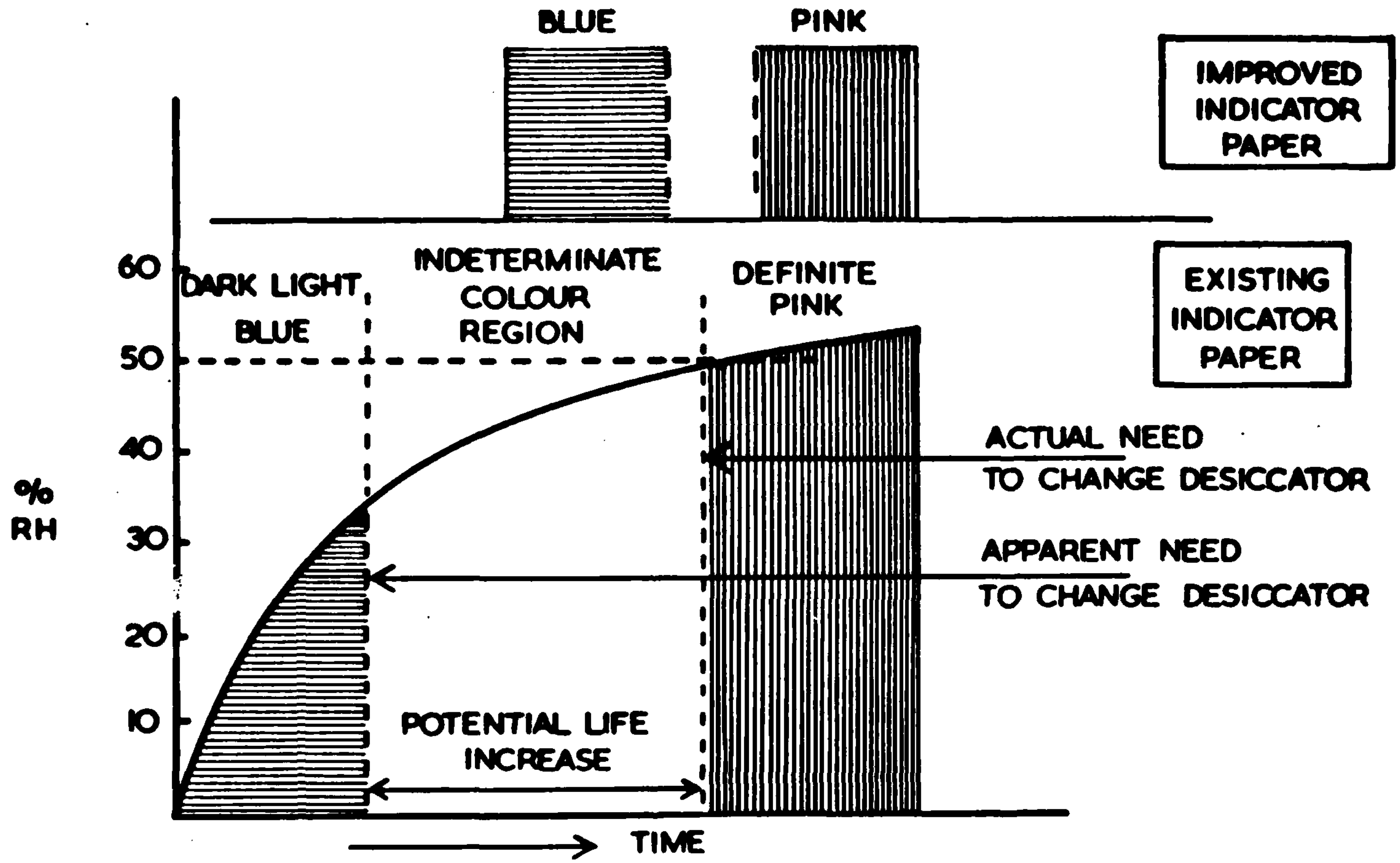


FIG. 7

ADVANTAGE OF AN IMPROVED HUMIDITY INDICATOR PAPER IN EXTENDING DESICCATOR LIFE

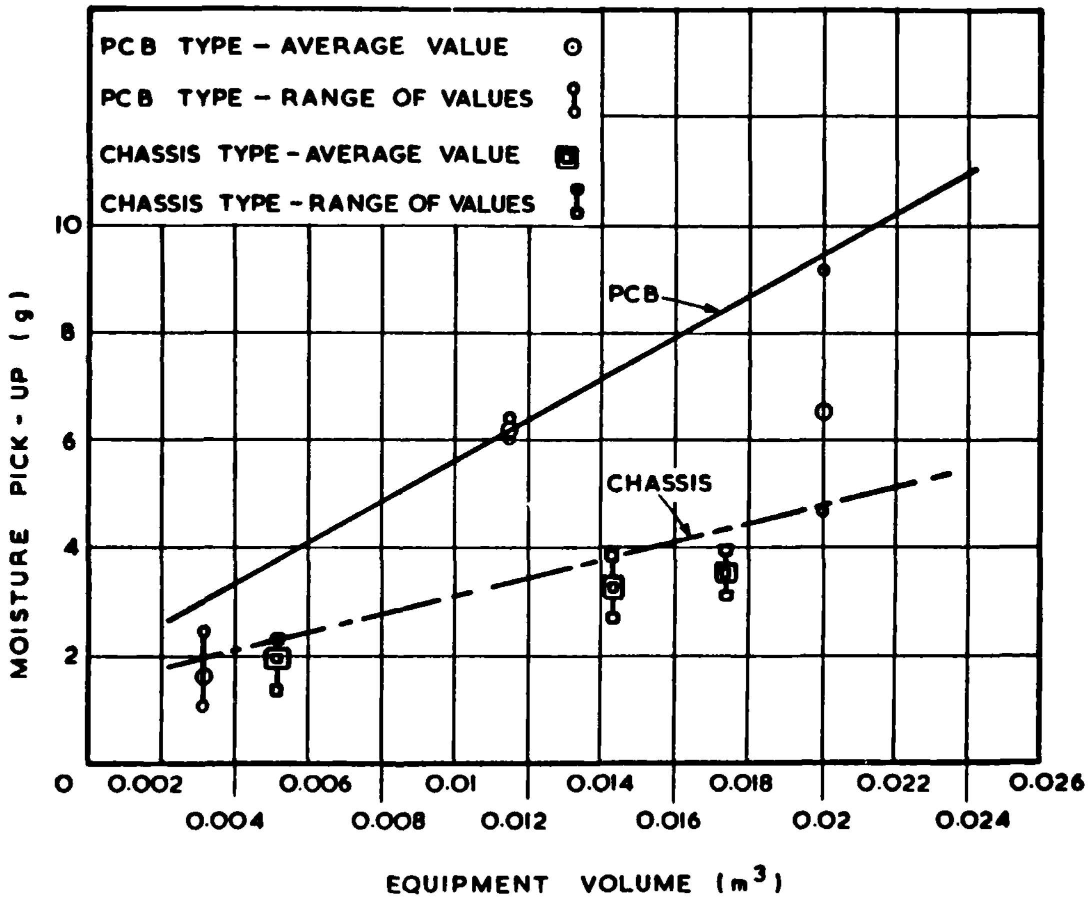
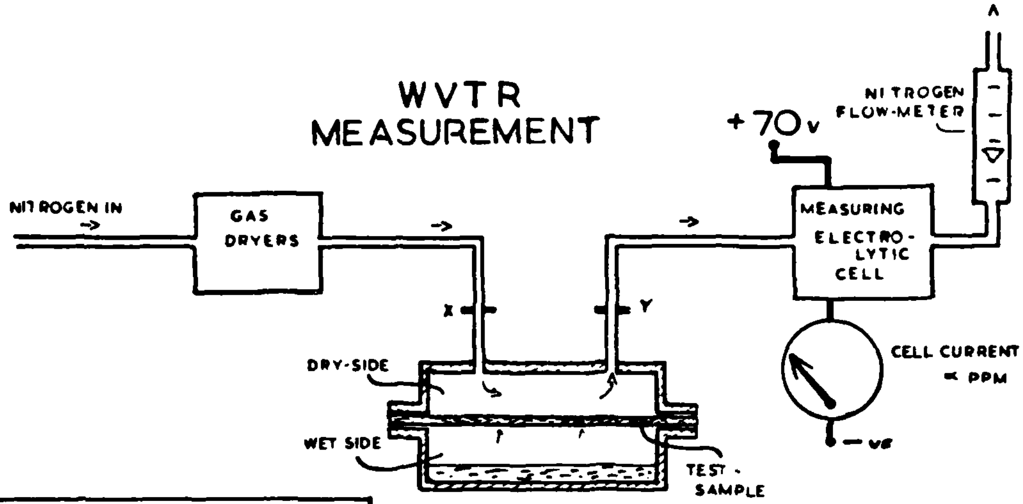


FIG. 8. MOISTURE PICK-UP IN RELATION TO EQUIPMENT VOLUME



SWEEP-GAS ELECTROLYTIC
HYGROMETER SYSTEM
- DIAGRAMMATIC

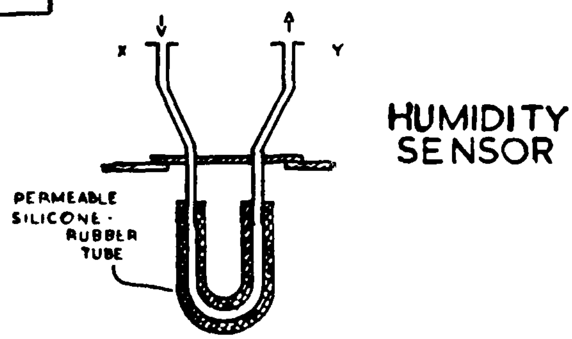


FIG. 9

TABLE 1

COMPARISON OF DESICCATOR CAPACITY WITH MOISTURE PICK-UP AFTER 14 DAYS DAMP HEAT

Equipment Identification	Moisture Capacity of Desiccator	Moisture Pick-up @ 30°C & 70% rh
TSR2 Unit	1.35	3.2
C 13 Radio	5.4	3.4
C 42 Radio	5.4	3.4
Rapier Distribution Box	1.35	1.9
Rapier Amplifier Control Box	1.35	1.5
Rapier Digital Computer Unit	5.4	6.5

TABLE 2

WATER VAPOUR BARRIER PROPERTIES OF PLASTICS FILM AND SHEET MATERIALS, CONSTRUCTIONAL COMPOSITES AND SEALING MATERIALS

(a) SHEET AND FILM MATERIALS

Units - grams per square metre per day at +38°C (100 -> 0% RH) referred to thickness of 0.25mm (0.010")*

POLYETHYLENE (POLYTHENE)	1.2 to 2.0
DOUBLE-ORIENTED POLYTHENE	0.6
PVC FILM UNPLASTICISED	2.8
PVC FILM PLASTICISED	12 to 70
PTFE	0.1 to 5.0
FLUORO-HALO CARBON FILM	0.1
FLUORO-CARBON POLYMER	0.5
VINYL CHLORIDE CO-POLYMER	2.5
POLYVINYL FLUORIDE	4.2
POLYVINYLIDENE DI-CHLORIDE	0.66
POLYESTER FILM / MELINEX -	3.0
MYLAR	3.6
SURLYN 'A' FILM	2.3
IONOMER RESIN FILM	0.02
VINYL ACETATE	4.5 to 8
ACLAR	0.2

* Thickness quoted for comparison purposes. Many of the materials are not available in this thickness. Actual WVTR = figure x $\frac{.010}{\text{thickness in inches}}$

(b) LAMINATED MATERIALS

PLASTICS/ALUMINIUM FOIL LAMINATES	0.03 to 0.3
POLYTHENE/ALUMINIUM FOIL/POLYTHENE	0.3
POLYESTER/ALUMINIUM FOIL/SARAN	0.05

TABLE 2

(c) THICK PLASTICS SHEET AND CONSTRUCTIONAL PLASTICS

Material	Thickness (mm)	WVTR @ 25°C & 100% RH
Glassfibre/Rigid Polyurethane Foam/Glassfibre Sandwich	16	1.7 g/m^2d
Glassfibre/Expanded Polystyrene/ Glassfibre Sandwich	16	1.5
ABS	3	0.8
GRP Epoxy and Polyester Resin	6	0.75 - 2.0
GRP (Printed Circuit Board Quality)	2.3	0.2
PPO	4.3	0.085
Polyethylene	3.4	0.052
High Density Polythene and Polypropylene	3.0	0.04

(d) GASKET MATERIALS AND 'O' RINGS

	Material	Thickness (mm)	WVTR @ 25°C & 100% RH
GASKETS	Expanded Natural Rubber	3	15 $g \times 10^{-4}$/ metre of seal length/day
	Expanded Neoprene	3	13
	Solid Rubber (hard)	3	12
	Solid Rubber (medium)	3	30
	Expanded PVC	6	24
	Expanded Silicone Rubber	3	66
	Cork, processed	2	72
'O' RINGS	Fluorocarbon Rubber	2.5mm dia	9.6 $g \times 10^{-4}$/ metre of seal length/day
	Nitrile Rubber	2.5	42.0
	Silicone Rubber	2.5	96.0
	Polyurethane Rubber	2.5	138

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DRYING OUT PROCEDURES

continue on separate piece of paper

Abstract

This memo reviews the problem of protecting Military electronic equipment, when deployed and in store from adverse climatic environments, the major factor being protection from the effects of water and water vapour in the atmosphere aided by temperature effects.

The effects of moisture on equipments, achieving and maintaining a dry interior, sealing standards, water vapour barriers, desiccation, drying-out procedures and humidity indication are considered, together with allied aspects.

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